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Original Research Paper

Evaluation of the Maturity of MSW Second-time Compost and Its Effect on the Growth of *Amorpha fruticosa* and *Festuca arundinacea*

Qingnan Yang, Xiaoping Guo†, Shuqi Wang and Zuguang Han
Beijing Forestry University, Key Laboratory of Soil & Water Conservation and Desertification Combating, Ministry of Education, Beijing, 100083, China
†Corresponding author: Xiaoping Guo

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ABSTRACT

This paper explores 9 different composting schemes to determine the optimal strategy to improve the compost maturity of municipal solid waste. The second-time compost, in the volume ratios of 0%, 25%, 50%, 75%, 100%, was used to plant *Amorpha fruticosa* and *Festuca arundinacea*. We measured emergence time and plant growth to determine the effect of the compost on the growth of *Amorpha fruticosa* and *Festuca arundinacea*. After fuzzy analysis, we found that maturity of T5 and T6 is the best, and compost maturity was optimal resulting from the process with no additional water, adding agents every 9 days, and turning every 3 days with an initial C/N of 20. The main factors affecting the degree of maturity are the initial C/N, followed by water situation, inoculated case, and turning frequency. The second-time compost allows reduction of soil heavy metal content and is conducive to *Amorpha fruticosa* survival and *Festuca arundinacea* germination. However, the high adding proportion of second-time compost delays the survival and emergence time, and also makes higher stems root ratio of *Festuca arundinacea*. The 50% and 75% proportion has higher seedling height and ground diameter growth of *Amorpha fruticosa*. The seedling height of *Festuca arundinacea* is better in the 75% proportion.

INTRODUCTION

Composting is one of the three major municipal solid waste disposal methods. The city of Beijing, China has a goal to achieve the relative amounts of waste incineration, composting, and landfill of 4 : 3 : 3 by "the 12th five-year-plan scheme". However, currently the amount of waste that is composting makes up a much smaller fraction of the total. One obstacle to composting is that there is no market for municipal solid waste coarse compost. Some is used as organic fertilizer, nutrient soil, road building material, or as soil additives for personal gardens. Additional compost is stored or ends up being transported to the landfill. However, the main factor restricting the popularization and the application of municipal solid waste coarse compost is its lack of the maturity. Because of unsophisticated methods of mixed municipal solid waste collection, composting technology and equipment etc., waste coarse compost is of limited maturity (Chen 2009, Yang 2009). Coarse compost produces harmful substances that may inhibit plant germination or hinder plant growth (Yin 2008). Ideally, long-term plans for compost quality improvement should include improvements to initial waste classification and improving composting equipment. However, more study of the composting process and determination of the effects of easy-to-manipulate variables such as water levels, the time of adding conditioners, or the frequency of turning may allow immediate improvements to composting. For example, the study of the effect of agents, heat and combined agents and heat on composting maturity of municipal solid waste (Zhang 2011), selection of vegetable seeds native in China instead of the cress seed to test the germination index (Liu 2012), effect of inoculating microorganisms (Ge 2011) or composting mixed with night soil on compost maturity of municipal solid waste (Du 2011).

China has made significant policy changes to protect the environment, such as vegetation restoration of abandoned mines, improving urban landscaping, and increasing highway greening. Regions with thin or barren soils often must be supplemented by addition of a large amount of soil from another location. However, this may be done without attention to the soil nutrient requirements, leading to nutrient levels being inadequate, which allows only poor plant growth. Planting turf in the nursery can be done, but it depletes limited resources of top soil. Therefore, such environmental remediation efforts are hindered by these problems of needing large amounts of non-abundant soil and needing to identify and treat problems of poor soil quality.

Carbon-nitrogen ratio, water content, oxygen content, conditioning agents of compost materials, all contribute to the degree of compost maturity. Waste from different regions and in different seasons, with different controlled parameters, will result in differences of maturity and quality. We first describe the physical, chemical, and biological factors that affect the compost maturity, and explore the second-time composting test as a method to improve the compost maturity of municipal solid waste. We propose that second-time compost with better maturity can be used in fields which need additional soil but have low requirements for the soil characteristics, such as for the re-vegetation of abandoned mines, highway greening, urban landscaping, and nursery.

TEST AND METHODS

The second-time composting test: The second-time composting test of municipal solid waste was done between March 24, 2014 to April 30, 2014 in the research base of ecological restoration of the Environmental Protection Research Institute of Light Industry in Machi Town, Changping District, Village ZiZhuang. Municipal solid waste coarse compost (from Beijing Asuwei Waste Treatment Plant) was the source of the composting materials. Sawdust and urea were used as conditioning agents to regulate C/N. The experiment of using four factors and three levels orthogonal was conducted as Table 1. There are total 9 treatment plans, T1-T9; T0 was coarse compost naturally stacked.

The C/N and water content of both conditioning agents and composting materials were measured before the test. First, we measured coarse compost and conditioning agent with a certain percentage, and placed the materials on a plastic sheet on the ground. The agents (chlorine was removed from water after activating for 30 min) were added, then mixed together with other materials. We adjusted the initial water content. The materials were piled to form some four pyramids with no top, 1.2 m of base length and 0.8 m in height, and then covered with plastic sheeting. The composting process lasted 36 days. Each treatment adds 0.03 g/Kg quantitative supplement agents according to the time indicated in Table 1. Each treatment was rehydrated to a moisture of 65%, and turned as scheduled.

Index analysis: We measured E_4/E_6 by TU-1810DS type ultraviolet visible spectrophotometer (Beijing Purkinje General Instrument CO.LTD). TOC was determined by volumetric method. TN was determined by Kjeldahl nitrogen method. NH_4^+-N was measured using indophenol blue colorimetric assay with an EN-030-02 -visible spectrophotometer (Shanghai Shunyu Heng -Scientific Instruments Ltd). We measured heavy metals, mercury, and arsenic by atomic fluorescence spectrometry (GB/T22105.1-2008, GB/ T22105.2-2008), lead and cadmium by graphite furnace atomic absorption spectrophotometry (GB / T17141-1997). We measured chromium by flame atomic absorption spectrophotometry (HJ491-2009). GI was measured by seed germination test. The second-time compost of dried samples was mixed with distilled water at 1g : 10mL, shaken and filtrated, with Sijiu oil green cabbage seed being cultivated (purchased from Guangzhou long seeds Ltd. co) at 25 ± 1°C, with a humidity of 80% for 48 hr.

Plant test: In order to validate the effect of second-time compost on the plant germination and growth, *Amorpha fruticosa* and *Festuca arundinacea* were planted outdoor in pot experiments. *Amorpha fruticosa*, with high resistance, is one of the pioneer species in North China being used not only for water and soil conservation but also for soil improvement. In addition to lawn planting, *Festuca arundinacea* is widely used for revegetation of mined areas and is used for ecological management at tailings. It is often planted together with other grasses. Plant growth experiments were completed from June 1, 2014 to August 16, 2014. Plastic flower pots were used of 35 cm (diameter)×23 cm (lower diameter)×27 cm (height) and 25 cm (diameter)×13 cm (lower diameter)×16 cm (height) to plant *Amorpha fruticosa* and *Festuca arundinacea* respectively. The second-time compost with the best maturity was filtered out to mix respectively 0%, 25 %, 50 %, 75 % and 100 % of the volume ratio with untreated mellow soil, which were experimental group. Control group was added coarse compost .The uniformly mixed matrix was put into the flowerpot to 2 cm below basin top without compaction. We sowed 150 *Festuca arundinacea* seeds and transplanted *Amorpha fruticosa* (about 1 m height ×1 cm diameter) seedlings to each pot. There were four experimental groups and four control groups for both *Amorpha fruticosa* and *Festuca arundinacea*. They are 25%, 50%, 75%, 100% and CK25%, CK50%, CK75%, CK100%, respectively. Each treatment was with three replicates selected randomly. We irrigated plants early in the morning during the growth phase, as needed, maintaining the same irrigation amount and time of each treatment.

Growth index monitoring: We recorded initial germination time, height, and diameter changes of *Amorpha fruticosa* and *Festuca arundinacea*'s seedling number and initial seedling emergence time. We selected 20 plants from each pot to measure the height of *Festuca arundinacea* and performed all measurements when emergence amount was less than 20 plants. We collected *Festuca arundinacea* above ground and underground parts after 43 days, then dried them to constant weight under the condition of 60°C and 105°C for 24 hr respectively. The stem root ratio was calculated (biomass dry weight of aboveground / biomass dry weight

Table 1: Orthogonal tests factors and levels $L_9(3^4)$ of second-time composting test.

	Initial C/N	Water situation (65%)	Inoculated case (0.03g/kg)	Turning frequency (Days/times)
T0	-	-	-	-
T1	11.4 (U)	Every 9 days	Every 9 days	3
T2	11.4 (U)	The 18th day	The 18th day	6
T3	11.4 (U)	No adding	No adding	9
T4	20.0 (S)	Every 9 days	The 18th day	9
T5	20.0 (S)	The 18th day	No adding	3
T6	20.0 (S)	No adding	Every 9 days	6
T7	15.7 (U&S)	Every 9 days	No adding	6
T8	15.7 (U&S)	The 18th day	Every 9 days	9
T9	15.7 (U&S)	No adding	The 18th day	3

U: urea; S: sawdust; U&S: urea and sawdust.

Table 2: Classification of compost maturity level.

Indicator	Good maturity level I	Maturity Level II	Basic maturity Level III	Not maturity Level IV
T value	0.48	0.48~0.56	0.56~0.63	>0.63
NH_4^+-N	0.4	0.4~0.6	0.6~0.8	>0.8
GI	80%	60%~80%	50%~60%	<50%
E_4/E_6	1.8	1.8~1.7	1.7~1.6	<1.6

of underground).

RESULTS AND ANALYSIS

Fuzzy Evaluation of Compost Maturity

Determine the fuzzy evaluation factors: The apparent index, C/N, GI, NH_4^+-N are commonly used as evaluation factors, but these are not rigorous means of assessment. For example, apparent index is generally determined by colour, smell, degree of attracting mosquitoes. But the compost colour is closely related to moisture. High water content may lead to darker colour. And there is not significant difference in colour with dry compost. Factors such as odour and degree of attracting mosquitoes are too subjective, so the apparent index is not suitable for evaluating compost maturity. Different composting materials often exhibit large differences in C/N. For example, municipal solid waste generally has low C/N. If we applied the commonly used maturity defining value of C/N , this compost would all mature. Thus, this is not a strict criteria. Instead, evaluating the compost treatments was by determining the values of T (the final C/N ratio/the initial C/N ratio). This parameter is less affected by the initial C/N. We also considered the E_4/E_6 as another factor. Although it is not commonly used, the ratio is more stable and reflects the optical properties of humic acid. Therefore, we selected four indicators from physical indices (E_4/E_6), chemical indices (T value, NH_4^+-N) and biological indices (GI) to assess maturity. We classified maturity degree into four grades in accordance with the preceding or conversion over (for example T value), as given in Table 2.

2 Establish membership function: We used the simplest linear triangle membership function model as follows.

$$\mu\ \text{small} = \begin{cases} 0 & x \geq \dfrac{a+b}{2} \\ \dfrac{\dfrac{a+b}{2} - x}{\dfrac{b-a}{2}} & a < x < \dfrac{a+b}{2} \\ 1 & x \leq a \end{cases}$$

$$\mu\ \text{medium} = \begin{cases} 0 & x \leq a \\ \dfrac{x-a}{\dfrac{b-a}{2}} & a < x < \dfrac{a+b}{2} \\ \dfrac{b-x}{\dfrac{b-a}{2}} & \dfrac{a+b}{2} \leq x < b \\ 0 & x \geq b \end{cases}$$

$$\mu\ \text{large} = \begin{cases} 0 & x \le \dfrac{a+b}{2} \\ \dfrac{x - \dfrac{a+b}{2}}{\dfrac{b-a}{2}} & \dfrac{a+b}{2} < x \le b \\ 1 & x > b \end{cases}$$

In the case of NH_4^+-N, the grade I, II, III, IV membership function are:

$$\text{I LEVEL } Y_{I} = \begin{cases} 1 & X \le 0.4 \\ 10(0.5-X) & 0.4 < X \le 0.5 \\ 0 & X > 0.5 \end{cases}$$

$$\text{II LEVEL } Y_{II} = \begin{cases} 10(X-0.4) & 0.4 \le X \le 0.5 \\ 5(0.7-X) & 0.5 < X \le 0.7 \\ 0 & X < 0.4,\ X > 0.7 \end{cases}$$

$$\text{III LEVEL } Y_{III} = \begin{cases} 5(X-0.5) & 0.5 \le X \le 0.7 \\ 10(0.8-X) & 0.7 < X \le 0.8 \\ 0 & X < 0.5,\ X > 0.8 \end{cases}$$

$$\text{IV LEVEL } Y_{IV} = \begin{cases} 0 & X \le 0.7 \\ 10(X-0.7) & 0.7 < X \le 0.8 \\ 1 & X > 0.8 \end{cases}$$

Calculate the corresponding membership function of T value, GI and E_4/E_6 accordance with the triangular membership function model. Bring corresponding observations into the membership function to get the membership matrix R.

Calculating the weight of evaluation factors:

$$Wi = \left(\frac{Ci}{Si}\right) / \sum_{i=1}^{m} \frac{Ci}{Si}$$

Wi is the weight of i-th evaluation factors; Ci is the evaluation factor of the i-th measured value; Si is the grading averages of i-th evaluation factor; m is the number of factors evaluated.

Calculate the weight of each factor, then compose fuzzy weights matrix W = {W1, W2, ..., Wm}

Results of fuzzy evaluation: Operate fuzzy complex operations of the membership matrix R and the weight matrix W, the results given in Table 3.

T4, T5, and T6 had the best compost maturity for grade I T4, compost grade I was 0.4712 less than T5 and T6 compost; T2, T8 compost were grade II; T9 has a basic compost maturity for grade III; T1, T3, T7 and coarse compost T0 did not reached maturity, so are IV grade.

As shown in Table 4, the order for A, B, C, D four factors is initial C/N> water situation > inoculation case > turning frequency. The best combination was the treatment with an

Table 3: Results of the fuzzy mathematics evaluation on coarse compost and second-time compost.

Groups	Maturity membership (I, II, III, IV)	Rank
T0	W·R=(0,0,0.0978,0.9022)	IV
T1	W·R=(0,0.0739,0.1879,0.7383)	IV
T2	W·R=(0,0.4533,0.2825,0.2642)	II
T3	W·R=(0.0883,0.1414,0.1507,0.6196)	IV
T4	W·R=(0.4712,0.3839,0.1574,0)	I
T5	W·R=(0.8999,0.1000,0,0)	I
T6	W·R=(0.8882,0.1119,0,0)	I
T7	W·R=(0.0162,0.1858,0.1656,0.6325)	IV
T8	W·R=(0.3140,0.3847,0.1910,0.1104)	II
T9	W·R=(0.2828,0.2859,0.3005,0.1310)	III

R: the membership matrix , W: the weight matrix.

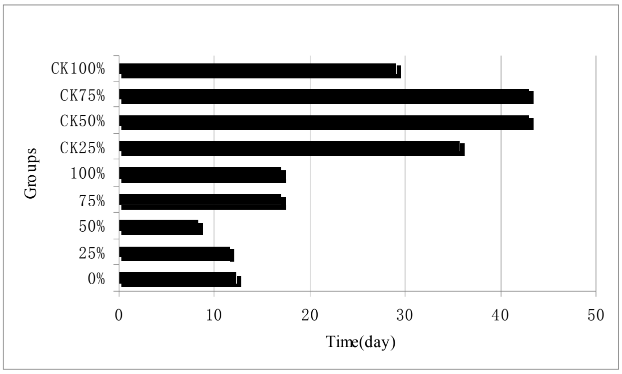


Fig. 1: The survival situation of *Amorpha fruticosa.*

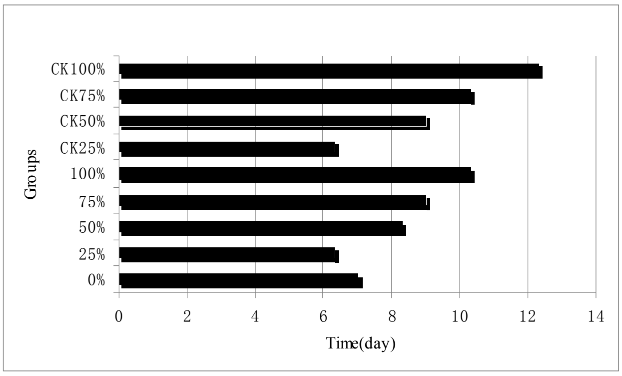


Fig. 2: The situation of *Festuca arundinacea* initial emergence time.

Table 4: Range analysis with second-time compost.

No.	Initial C/N	Water situation (65%)	Inoculated case (0.03 g/kg)	Turning frequency	Result
	A	B	C	D	
T1	11.4(U)	Every 9 days	Every 9 days	3 days	0
T2	11.4(U)	The 18th day	The 18th day	6 days	0
T3	11.4(U)	No adding	The initial adding	9 days	0.0883
T4	20.0(S)	Every 9 days	The 18th day	9 days	0.4712
T5	20.0(S)	The 18th day	The initial adding	3 days	0.8999
T6	20.0(S)	No adding	Every 9 days	6 days	0.8882
T7	15.7(U&S)	Every 9 days	The initial adding	6 days	0.0162
T8	15.7(U&S)	The 18th day	Every 9 days	9 days	0.3140
T9	15.7(U&S)	No adding	The 18th day	3 days	0.2828
K1	0.0883	0.4874	1.2022	1.1827	
K2	2.2593	1.2139	0.7540	0.9044	
K3	0.6130	1.2593	1.0044	0.8735	
k1	0.0294	0.1625	0.4007	0.3942	
k2	0.7531	0.4046	0.2513	0.3015	
k3	0.2043	0.4198	0.3348	0.2912	
Poor R	0.7237	0.2573	0.1494	0.1031	
Order		A>B>C>D			
Optimal levels	A2	B3	C1	D1	

U: urea; S: sawdust; U&S: urea and sawdust.

Table 5: Heavy metal content and grade of coarse compost and second-time compost.

	Pb mg/kg	Cd mg/kg	As mg/kg	Hg mg/kg	Total Cr mg/Kg
Coarse compost	94.5	0.22	5.56	1.58	153
Level	Level 1	Level 2	Level 1	/	Level 2
Second-time compost	78.8	0.18	5.82	1.15	169
Level	Level 1	Level 1	Level 1	Level 3	Level 2

The grade is according to the soil environmental quality standards (GB15618-1995).

Table 6: LSD multiple comparisons of the experimental group and control group.

Groups	75%	100%	0%	25%	50%	CK50%	CK75%	CK25%	CK100%
Amorpha fruticosa germination time	17.0a	17.0a	12.3a	11.7a	8.3a	43.0a	43.0a	35.7a	29.0a
Groups	100%	75%	50%	0%	25%	CK100%	CK75%	CK50%	CK25%
Festuca arundinacea emergence time	10.3a	9.0ab	8.3abc	7.0bc	6.3c	12.3a	10.3b	9.0b	6.3c
Groups	100%	75%	50%	0%	25%	CK75%	CK50%	CK25%	CK100%
Festuca arundinacea height	20.39a	13.32b	13.20b	12.68b	10.92b	14.65a	11.20b	10.71b	9.55b
Groups	100%	75%	50%	0%	25%	CK75%	CK50%	CK100%	CK25%
*Festuca arundinacea*stem root ratio	0.920a	0.777ab	0.710ab	0.550ab	0.451bc	1.120a	0.872a	0.782a	0.623a
Groups	75%	50%	0%	25%	100%	CK100%	CK25%	CK50%	CK75%
*Amorpha fruticosa*height increment	0.597a	0.560a	0.557a	0.423a	0.360a	0.323a	0.133a	0a	0a
Groups	50%	0%	75%	100%	25%	CK100%	CK25%	CK50%	CK75%
*Amorpha fruticosa*diameter increment	0.425a	0.327a	0.307a	0.274a	0.242a	0.170a	0.058a	0a	0a

initial C/N of 20, no additional water, adding agents every 9 days, and turning every 3 days .

Heavy Metal Analysis

According to the soil environmental quality standards (GB15618-1995), the grade of heavy metal content of the coarse compost and second-time compost, is shown in Table 5.

After second-time composting test, the classification of the cadmium content was changed from level 2 to level 1 and

Table 7: LSD multiple comparisons of second-time compost and coarse compost in the same proportion.

	25% and CK25%	50% and CK50%	75% and CK75%	100% and CK100%
Amorpha fruticosa germination time	0.007**	0.000**	0.004**	0.143
Festuca arundinacea emergence time	1.000	0.489	0.174	0.048*
Festuca arundinacea height	0.845	0.079	0.230	0.000**
Festuca arundinacea stem root ratio	0.575	0.599	0.271	0.653
Amorpha fruticosa height increment	0.041*	0.000**	0.000**	0.784
Amorpha fruticosa diameter increment	0.027*	0.000**	0.001**	0.190

* means p<0.05, ** means p<0.01.

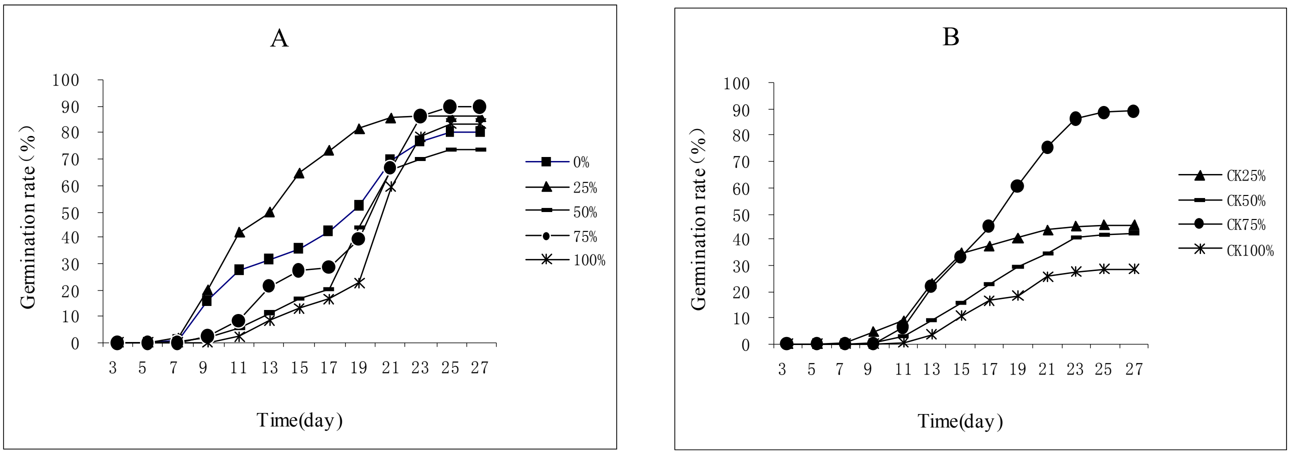


Fig. 3: (A) *Festuca arundinacea* germination time with experimental group and (B) *Festuca arundinacea* germination time with control group.

the mercury content level was changed from excessive level to level 3. The heavy metals limits all met meet level 3 classification or above of the second-time compost.

Plant Growth Indicators

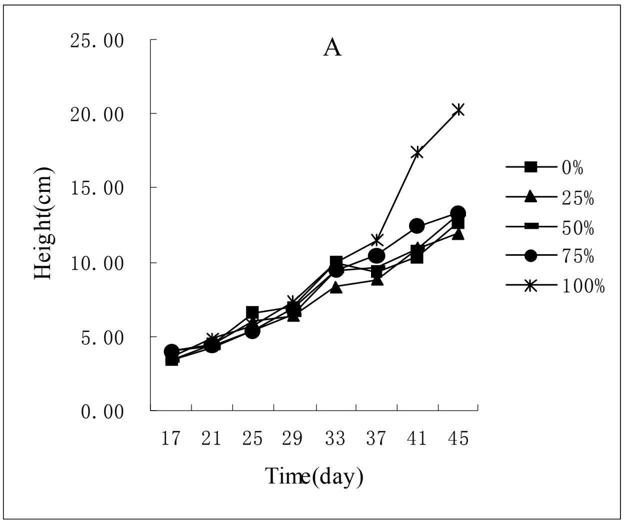
After LSD multiple comparisons for plant growth index, the results are presented in Table 6 and Table 7.

Amorpha fruticosa survival time in the experimental group was less than 20 days with a survival rate of 100% (Fig. 1). The treatment with an addition of 25% to 50% of the second-time compost showed earlier survival time than untreated mellow soil. Hence, the low addition ratio can stimulate germination of *Amorpha fruticosa* and the high addition ratio can delay the germination slightly with no effect on survival time of *Amorpha fruticosa,* which is about 30 days in the control group, and 10-30 days later than that of experimental group. CK50% and CK75% of *Amorpha fruticosa* died with no shoots. By LSD multiple comparison, there was significant difference between 25% and CK25 %, 50% and CK50 %, 75% and CK75 % (p<0.01).

Adding conditions showed *Festuca arundinacea* initial emergence time between 6-13 days (Fig. 2). With increasing amount of compost, the initial emergence time extended. Except for the 25% and CK25% treatments, the other treatments showed delayed initial emergence time compared to the untreated mellow soil. With the same proportion added, the experimental group showed earlier initial emergence time than the control group. Pairwise comparisons showed that the 0% and 100% treatments, the 25% and 75% treatments, the 25% and 100% treatments, and the 100% and CK100% treatments were significantly different (p<0.05). There were significant differences between the other treatments in the control group except CK50% and CK75% (p<0.05).

The rate of *Festuca arundinacea* germination was highest between 70%-90%, where 75% reached the highest germination rate of 90.1% in the experimental group (Fig. 3). The CK75% group's germination rate was 89.4%, but the remaining processing germination rates were less than 50%. The processing of germination rate from high to low was 75% > 25% > 100% > 50%, CK75 % > CK25 % > CK50 % > CK100 %.

The 100% treatment showed a rapidly increasing height of *Festuca arundinacea* in late growth stage (Fig. 4) and significant differences (p<0.01) with other treatments of the experimental group, but the other treatment groups showed more



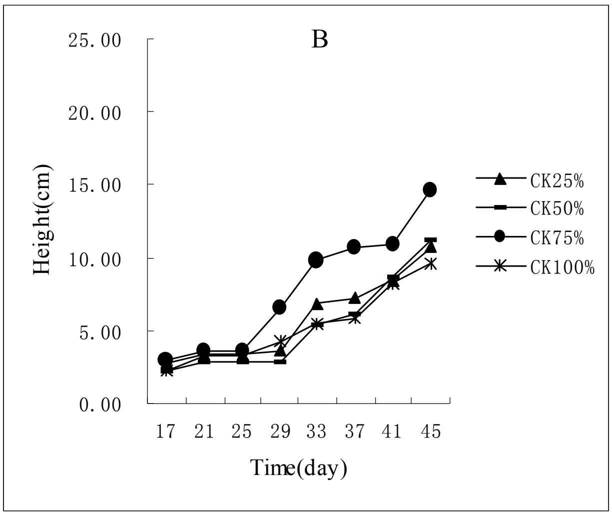


Fig. 4: (A) *Festuca arundinacea* height changes in experimental group after 43 days and (B) *Festuca arundinacea* height changes in control group after 43 days. Experimental conditions: open field and irrigation with actual demand from June 1, 2014 to July 13, 2014.

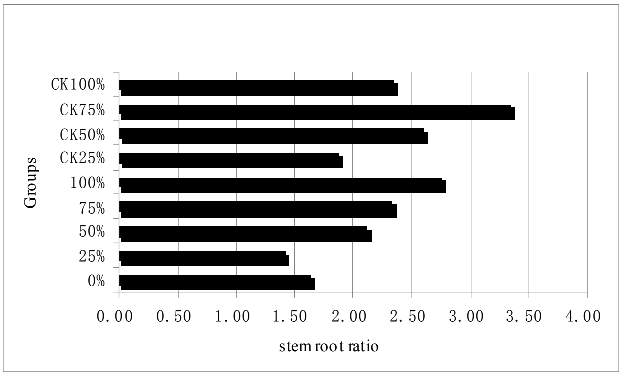


Fig. 5: *Festuca arundinacea* stem root ratio after 43 days.

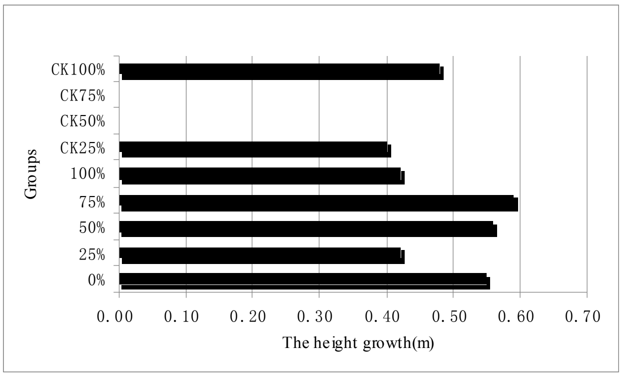


Fig. 6: The height growth of *Amorpha fruticosa* seedlings after 77 days. Experimental conditions: open field and irrigation with actual demand from June 1, 2014 to August 16, 2014.

consistent height changes. The seedling height of CK75 % processing was higher than that in other groups and were different from CK25 %, CK50 %, CK100 %. The differences between processing of CK25 % and 25%, 100% and CK100 % were significant ($p<0.05$).

All but one 25% treatment groups showed stem root ratios greater than the untreated mellow soil in the experimental group (Fig. 5), and the stem root ratio increased slightly with the increase starting 25% in the proportion of added compost, but only treatments between 25% and 100% had significant differences ($p<0.05$). The stem root ratios of experimental group greater than the control group in the same proportion of added compost.

As shown in Fig. 6 and Fig. 7, there are no differences in the height and the ground diameter in the experimental group and the control group of *Amorpha fruticosa* seedlings, respectively. Treatment of 75% showed the greatest growth. Diameter growth was highest with 50% processing. *Amorpha fruticosa* did not survive the CK50% and CK75% treatments. The 25% and CK25 % treatments, the 50% and CK50% treatments , the 75% and CK75 % treatments showed differences between both seedling height and ground diameter.

CONCLUSIONS

The second-time composting can increase the maturity of municipal solid waste coarse compost. The most important factor for better maturity is to increase the C/N ratio of composting material as the ratio of municipal solid waste coarse compost decreases. There is no need of water during composting process when the initial water content of the

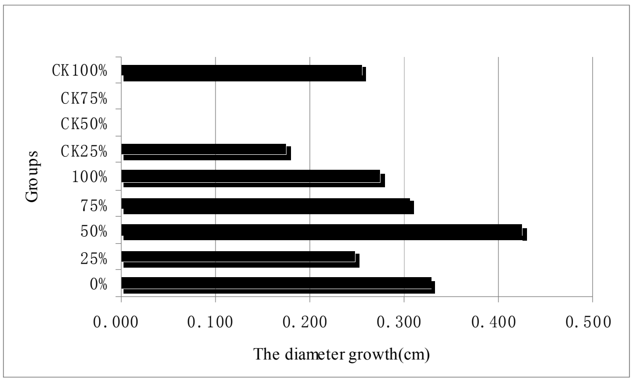


Fig. 7: Diameter growth of *Amorpha fruticosa* after 77 days. Experimental conditions: open field and irrigation with actual demand from June 1, 2014 to August 16, 2014.

compost material is well-adjusted. Agents supplementing and the turning of the composting body should be done to ensure adequate oxygen content. The second-time composting reduced the content of heavy metals to meet the third and above class of Chinese national standards, therefore the second-time compost can be used for plant cultivation in agroforestry without concern for heavy metal pollution.

The second-time compost promotes survival of *Amorpha fruticosa* unlike coarse composts. A lower adding proportion can increase growth of *Amorpha fruticosa* while a higher one delays growth. Greater growth in height and ground diameter of *Amorpha fruticosa* occurred at 50% and 75% of the second-time compost. *Festuca arundinacea* seeds sowed on the second-time composts-added had a higher germination rate than those on coarse composts-added ones. As the adding proportion of composting material increased, the period of inchoate germinating became longer and the shoot-root ratio became higher. When this occurred, an imbalance resulted between overground body and underground material, and the roots seemed to be weaker. In other words, a higher proportion of added compost may cause good early growth but hinder later growth. *Festuca arundinacea* sowed with the second-time composts had higher ratios and those sowed with coarse composts had weaker roots. When the adding proportion is 75%, *Festuca arundinacea* had the highest height. When contrasted with *Amorpha fruticosa*, *Festuca arundinacea* exhibited lower sensitivity to cultivating matrix, and grew well in higher proportions of compost.

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